TE 362

LECTURE 2:

Passive Devices

2016.01.20

Abdul-Rahman Ahmed

Impedance Characteristics

KNUST
Telecomm.
Engineering

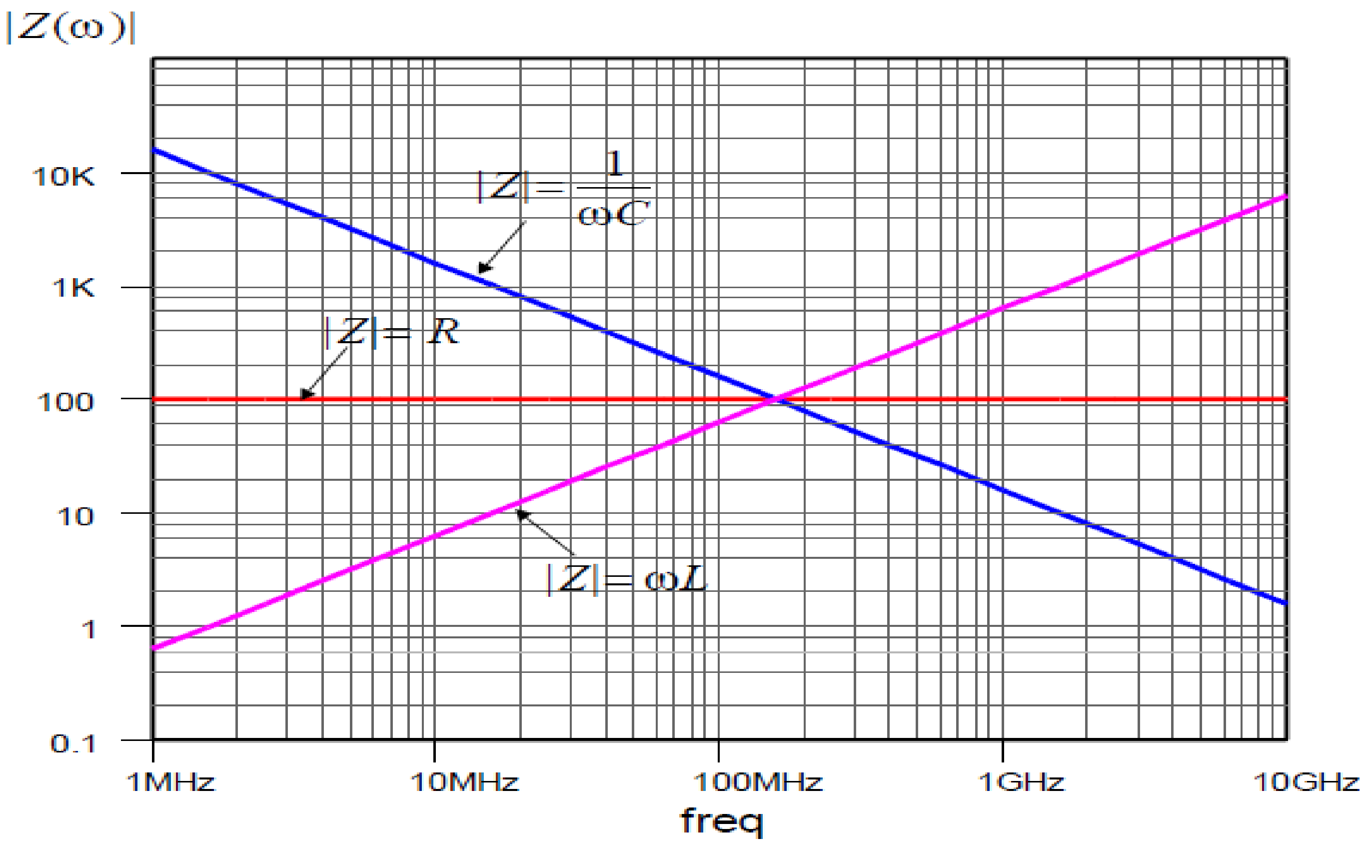
- Passive devices include resistors, capacitors, and inductors.
- When these are used in a circuit, the most fundamental consi-deration is their impedance.
- The impedance of resistor, capacitor and inductor, are respect -tively expressed as below:

$$Z_R = R$$

$$Z_C = \frac{1}{j\omega C}$$

$$Z_L = j\omega L$$

Plot of the Magnitude of the Impedances on a Log-Log Scale



- Impedances of resistor, capacitor and inductor

Impedance Characteristics vs Frequency

- Commercially available resistors, capacitors and inductors, may have non-ideal characteristics.
  - the impedance characteristic generally becomes more complicated as frequency increases, and
  - it becomes necessary to examine their characteristics in advance during circuit design.

Impedance Characteristics vs Frequency

- At low frequencies,
  - The passive devices exhibit the ideal impedance characteristics;
  - however, a very complicated equivalent circuit is needed in practice for their representation as the frequency increases,
  - adding to the difficulty and complexity of the circuit design.

Impedance Characteristics vs Frequency

- In such circumstances,
  - the equivalent circuit that properly reflects these characteristics in the frequency band of operation should be used in the circuit design.
- Understanding of
  - typical equivalent circuit of such commercially available passive devic es, and
  - the technique to determine the equivalent circuit values with a given data is basic.

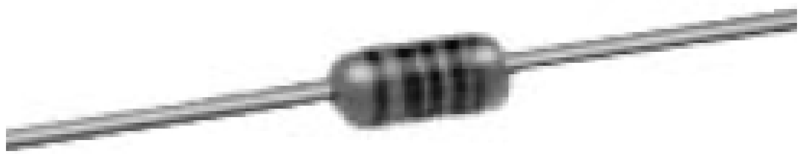
Impedance Characteristics vs Frequency

- Typical forms of data are available as datasheets and library in design software.
- When data are not available,
  - measurements or
  - EM simulations can be done to determine the equivalent circuits.

Classification of Passive Devices

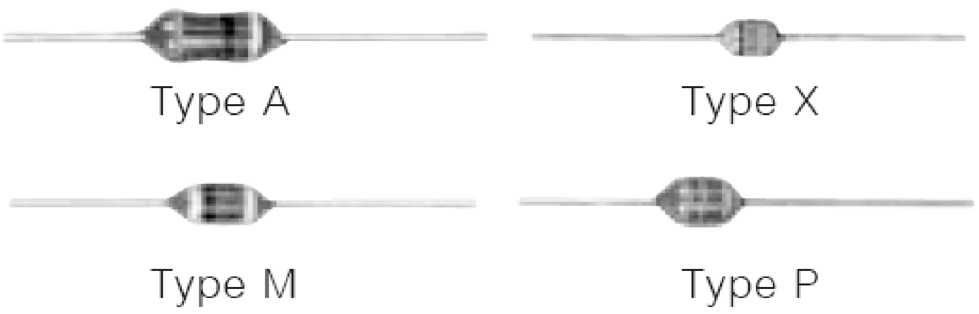
- Passive devices
  - are largely classified based on the fabrication method, and are divided into:
  - ***lead components,***
  - ***chip-type components***, and
  - ***passive components formed by patterns***.
- Lead-type and Chip-type components are widely available commercially

Lead-type Passive Devices



(a)

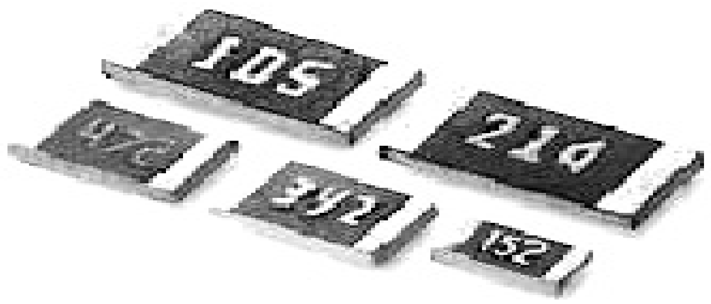
(b)



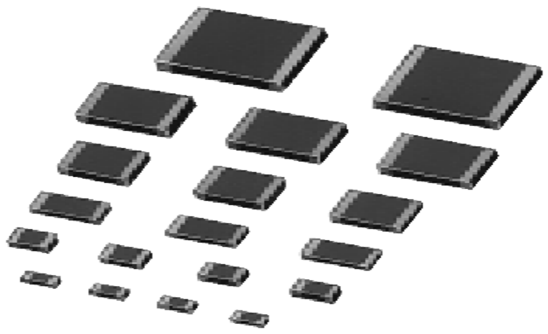
(c)

(a) resistor
(b) capacitor
(c) inductor

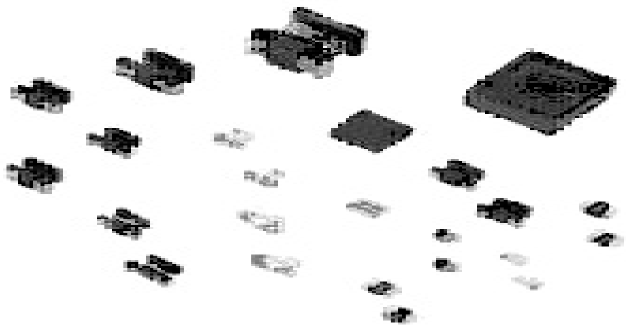
Chip-type Passive Devices



(a)



(b)



(c)

(a) resistor
(b) capacitor
(c) inductor

Assembly of Lead-type Component

- Lead-type components are assembled by insertion
  - The lead terminals are first bent and inserted into through-holes made in the printed circuit board.
  - The lead terminals are then cut, and
  - the printed circuit board with lead type components is dipped into melt solder.
  - Finally, the lead terminals are soldered to the round conductor patterns formed around the through-holes.

Lead-type Component

- Lead terminals of lead-type components
  - do not only serve the purpose of connection.
  - They also give rise to parasitic inductance for example at high frequencies, and
  - consequently this adds to the impedance of the passive device.
- These lead-type components were mostly used before chip-type components became commercially popular.
- Generally, they are bigger than chip-type components

Assembly of Chip-type Components

- Chip-type components are assembled by surface mounting technique (SMT).
- Solder creams are first printed to land-patterns formed on a printed circuit board or substrate, and
- chip-type components are mounted on the land patterns man ually or automatically.
- Finally soldering to the land-patterns is completed by
  - assing through reflow machine with appropriate temperature profile

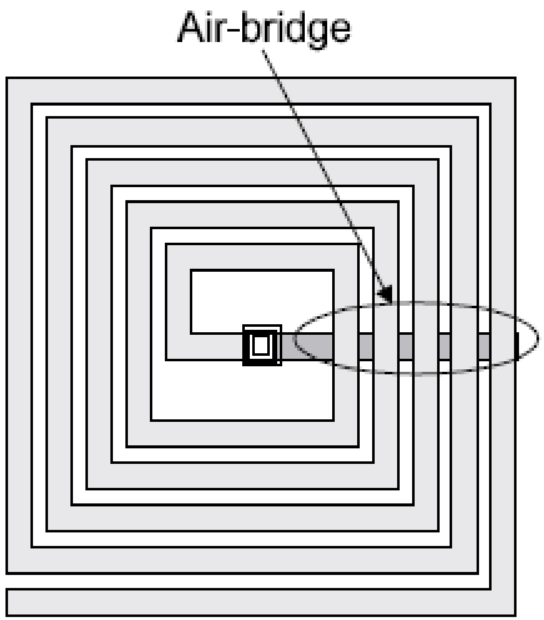
Chip-type Components

- Chip-type components compared to lead-type components
  - have relatively less parasitic elements caused by the terminals,
  - which becomes profitable at high frequency.
- The key reason for the popularity of these devices is
  - ***miniaturization***
  - ***surface-mounting feature***
  - rather than their advantage for use at high frequency.
  - SMT provides an advantage in large-scale fabrication.

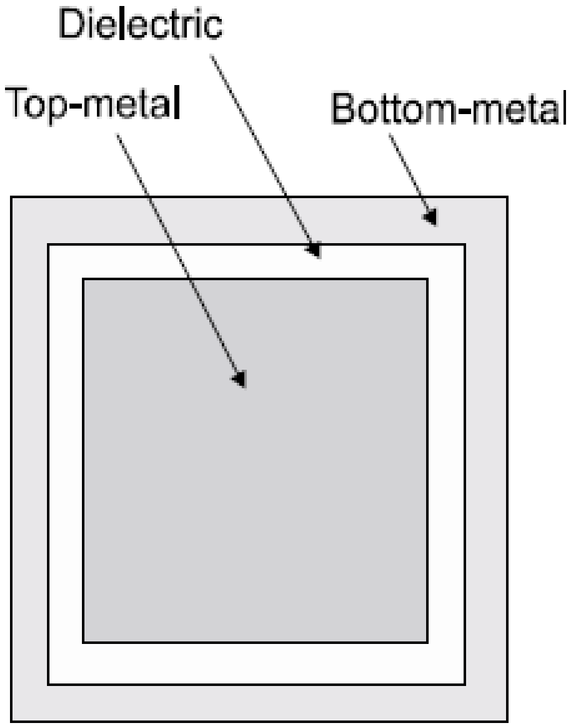
Pattern-formed Passive Components

- Pattern-formed passive components:
  - can be produced on the substrate
  - usually by the process of Monolithic Microwave Integrated Circuit (MMIC) or
  - thin film.
- passive devices by pattern formation
  - Are limited in the range of values attainable compared to chip-type or lead type devices,
  - which is a disadvantage.

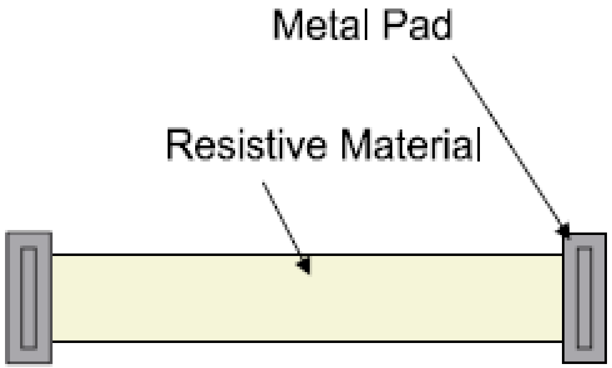
Pattern-formed Passive Components



(a) inductor



(b) capacitor



(c) resistor

Pattern Formed Resistor Components

- Resistors
  - A thin film of a resistive material (usually NiCr and TaN) forms the pattern, on which
  - the conductor pattern (for the purpose of connection) is produced by proper technique.
- The resistor has a uniform thickness

Pattern Formed Resistor Components

- The resistance is thus
  - proportional to the length *L* and
  - inversely proportional to the width (*W*).
  - The proportionality constant is defined as the *sheet resistivity* R_s, and t he resistance *R* is given by:

$$R = R_s \frac{L}{W}$$

; R_s has the dimension of ohms/square

Pattern Formed Capacitor Components

- Capacitor
  - A uniform thickness dielectric sheet is formed on the bottom cond-uctor pattern.
  - A top conductor pattern is again formed on the dielectric, and
  - a Metal-Insulator-Metal (MIM) capacitor is formed.
- At this point the dielectric material's thickness,
  - generally determined by the process, and
  - is constant

Pattern Formed Capacitor Components

- once the *sheet capacitance* C_s has been determined,
- the capacitance is then directly proportional to the surface area (A) and is expressed as:

$$C = C_S A$$

Pattern Formed Inductor Components

- Inductor
  - Its design is not as simple as that of capacitor or resistor.
  - Foundry service companies usually provide measurement results or data on several configurations of inductors; and
  - in the absence of those, the values of inductors are determined thro-ugh Electro-Magnetic (EM) simulation.

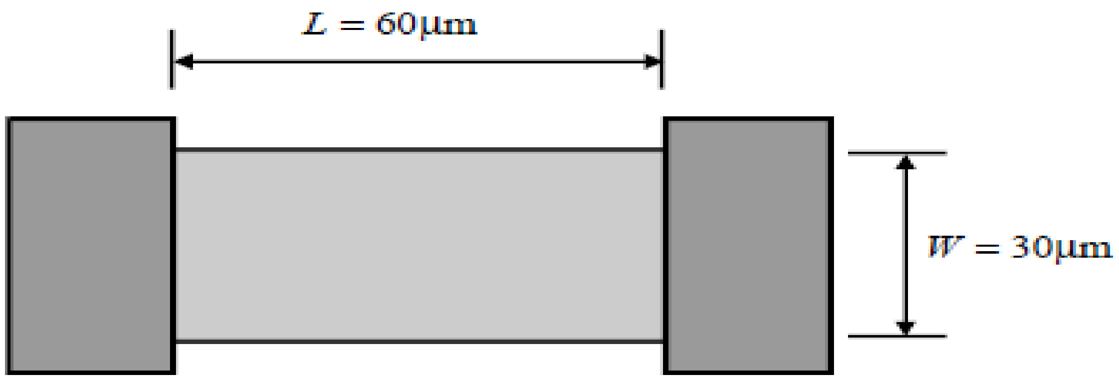
Pattern Formed Inductor Components

- When viewed from design point of view,
  - the construction of their equivalent circuit is the same as that of chip-type or lead-type components.
- NOTE: The parasitic characteristics increase with frequency

Example 1

KNUST
Telecomm.
Engineering

- Given that the sheet resistance R_s is 50 ohm/square meter, ca-lculate the resistance of the component shown below.
- In addition, the permittivity of a capacitor is 7.2 and its thickn ess is 0.4 μm; determine the sheet capacitance in pF/mm and hence calculate the capacitance of a 50 μm^2 capacitor.



Solution 1

$$R = R_S \frac{L}{W} = 50 \times \frac{60}{30} = 100\Omega$$

- For the capacitor, the sheet capacitance per square mm is;

$$C_S = \varepsilon_r \varepsilon_0 \frac{A}{t} = 8.854 \text{ pF/m } \times 7.2 \times \frac{1 \text{ m}^2}{0.4 \text{ m}}$$

$$= 8.854 \text{ pF/m } \times 7.2 \times \frac{1 \text{ m}}{0.4} \approx 159 \text{ pF}$$

- Thus, C_s= 159 pF/mm^2 and for a capacitor having an area of $50\mu m$ x $50\mu m$ is; $C = C_S \times 0.05^2 = 159 \times 0.05^2$ pF=0.398 pF

Equivalent Circuit of Chip-type Passive Devices

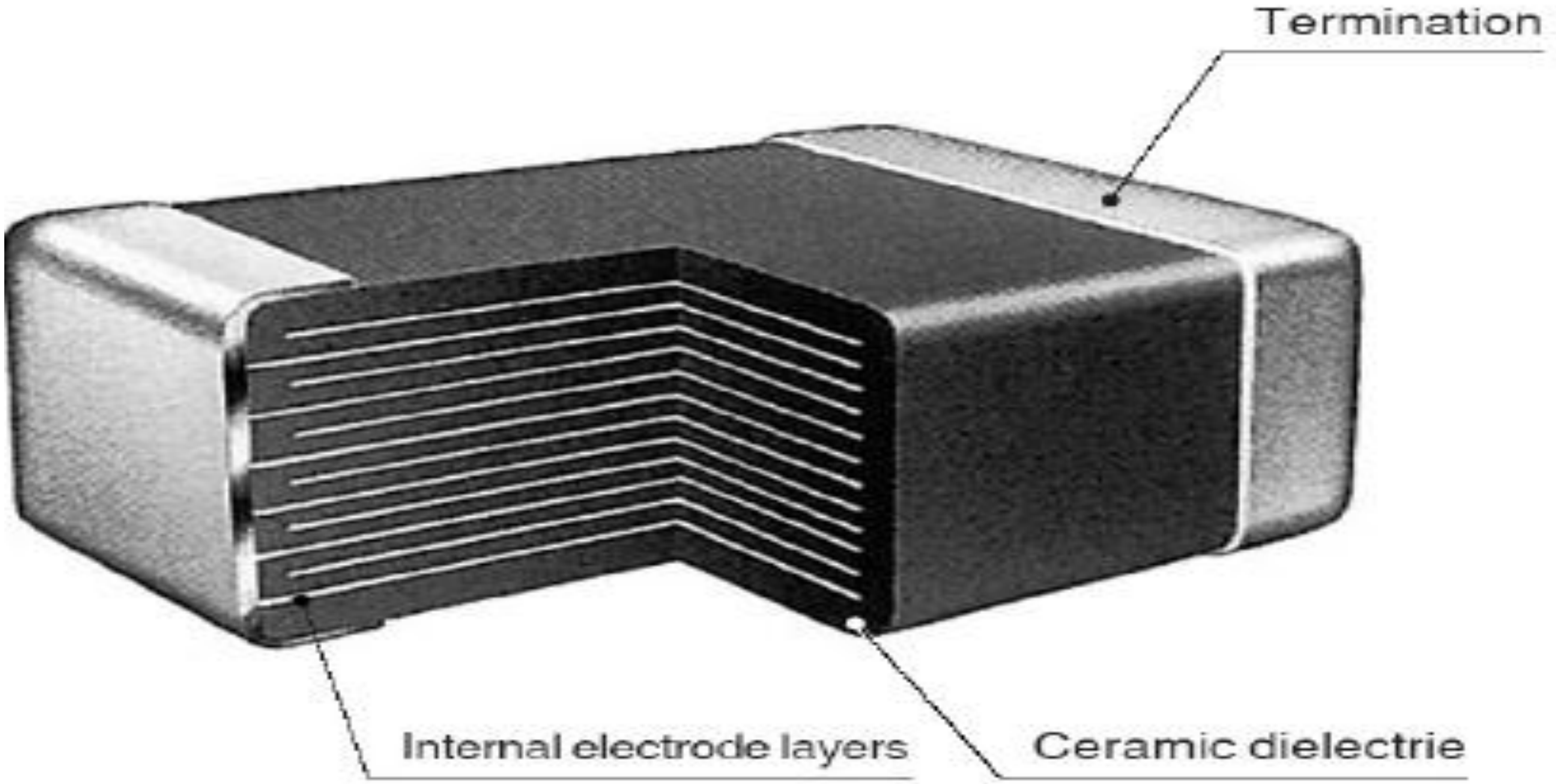
- In cases where thin film or MMIC process is not used,
  - the most likely choice for high frequency application is chip-type components and thus
  - they are widely used.
- chip-type device manufacturing and evaluation method will be discussed.
- In addition, the method of extracting the equivalent circuit from given data will be explained

Chip-type capacitor

- The chip capacitor is usually constructed in a multi-layer structure.
- The two soldered terminals are connected in parallel to a number of conducting plates, named as internal electrodes.
- The sum of the capacitance formed between the conducting plates appears at the terminals of the capacitor.
- The dielectric constant of the insulator filling the space between the conducting plates further increases the capacita-nce between the terminals.

Structure of a Chip Capacitor

KNUST
Telecomm.
Engineering



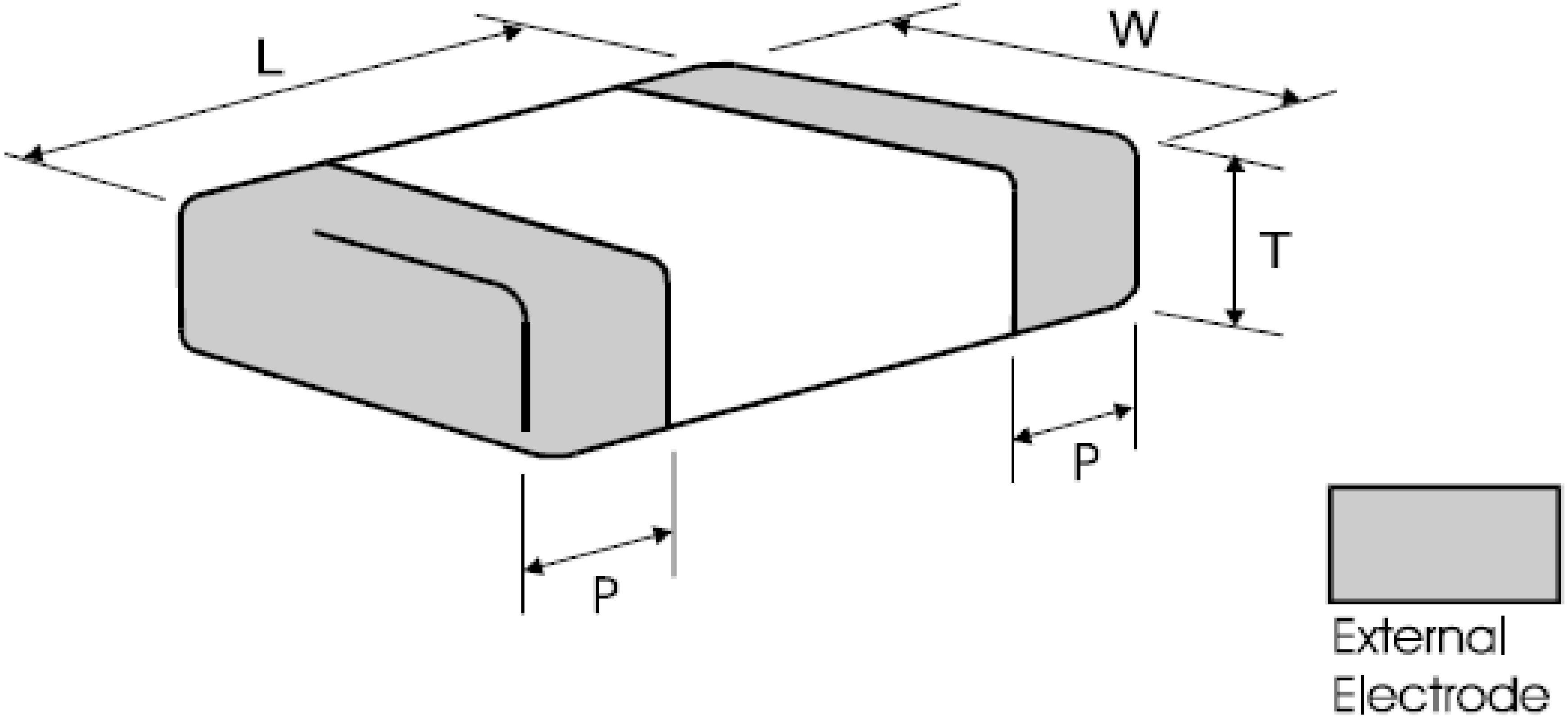
Dimensioning of Chip-type Component

- They are identified based on two parameters;
  - length *L* between the terminals and
  - the terminal width, *W*.
- Based on a standard unit of mm;
  - a capacitor having a length of 1.0 mm and a width of 0.5 mm,
  - is called type 1005; and following a similar definition,
  - type 1608 is a capacitor which has a length of 1.6 mm and a width of 0.8 mm.

Dimensioning of Chip-type Component

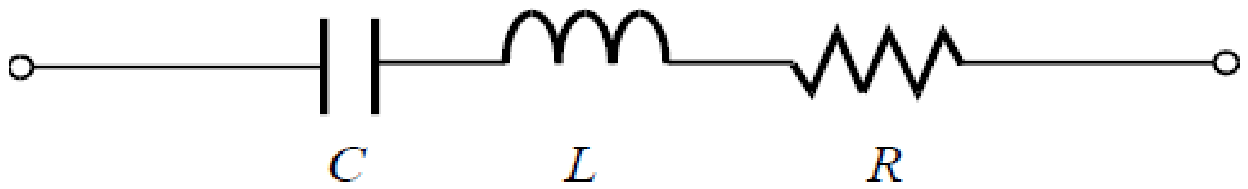
- This classification applies to capacitors, resistors and inductor s;
- for example,
  - a 1608 resistor similarly represents a chip resistor with a dimension of 1.6 mm length and 0.8 mm width.

Dimensions of a Chip-type Component



Equivalent Circuit of a Chip Capacitor

KNUST Telecomm. Engineering



C: capacitance of the capacitor

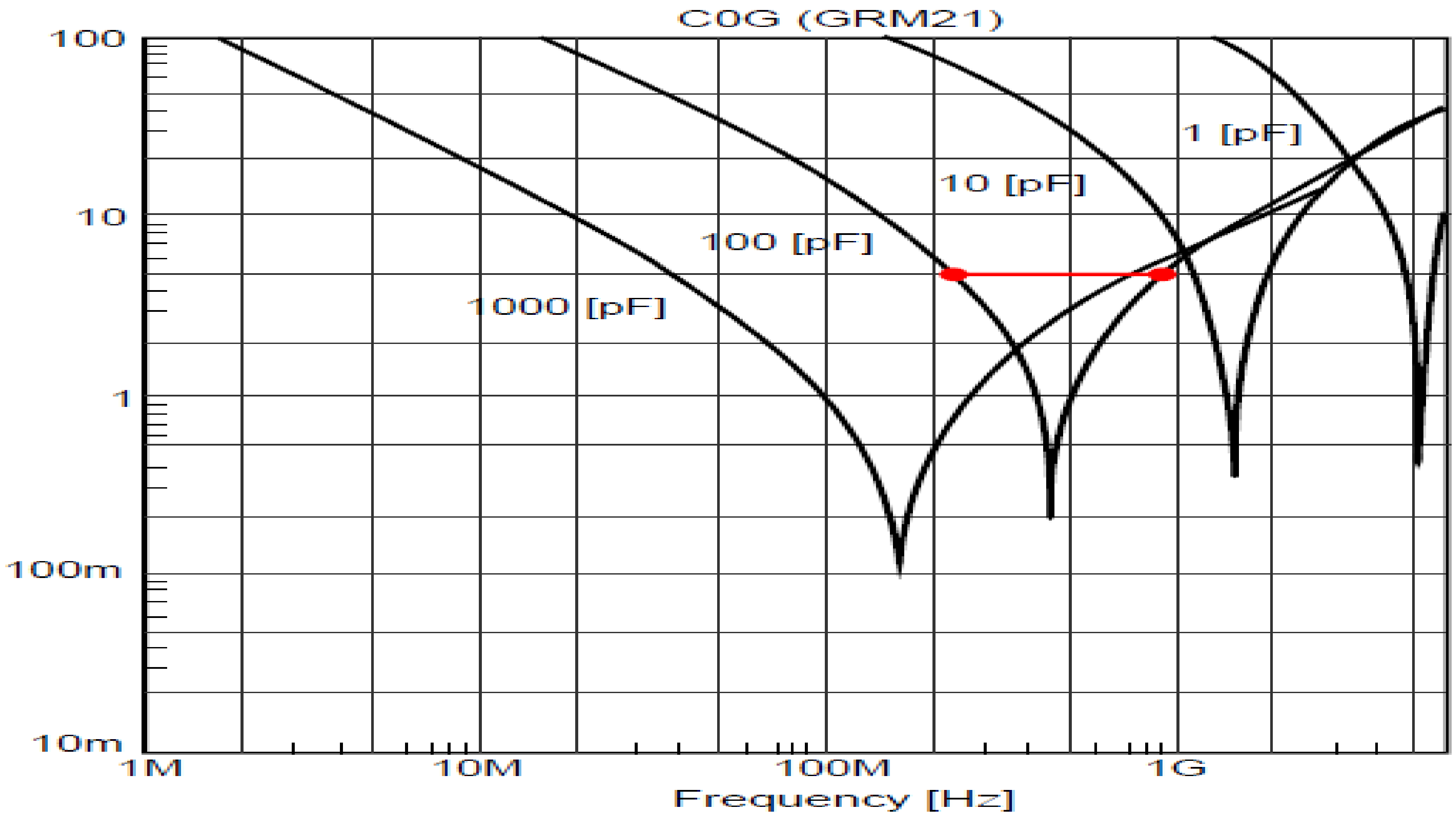
L: parasitic inductance (0.7 nH ~ 1 nH)

R: represents the loss of conductor plate

- From the structural point of view,
  - as the size of the capacitor becomes smaller, generally the inductance also becomes smaller, and
  - With further reduction, the inductance generally tends to be constant regardless of the value of the capacitance.

Impedance Characteristics with Frequency

KNUST Telecomm. Engineering



Impedance Characteristics with Frequency

KNUST Telecomm. Engineering

- Looking at the 100 pF curve,
  - below a 100 MHz frequency, it can be seen that the impedance decreases linearly with frequency.
  - This is so because at low frequency, it behaves as a capacitor; and
  - since at 70 MHz, it shows about an impedance of 20 ohms,
  - it can be seen to have a capacitance value of:

$$C = \frac{1}{2\pi f X_C} \cong \frac{1}{2\pi \times 70 \times 10^6 \times 20} = \frac{1000}{2\pi \times 1.4}\ \text{pF} \cong 113\ \text{pF}$$

Impedance Characteristics with Frequency

- The error in the calculated capacitance if any
  - will be due to the approximation in the reading of the impedance value from the graph.
- As the frequency increases,
  - the impedance after reaching a minimum rises again.
- While the impedance of the capacitor
  - is decreasing,
  - that of the inductor is increasing with frequency,

Impedance Characteristics with Frequency

KNUST Telecomm. Engineering

- thus, as the frequency becomes much higher,
  - the capacitor behaves as an inductor,
  - which explains why the impedance increases with frequency.
- Considering the minimum point of the 100 pF curve,
  - the resistor in the equivalent circuit is found to have a series resistance value of approximately $R = 0.2$ ohm.

Impedance Characteristics with Frequency

- Although the value of the inductor
  - is inaccurate only with this data,
  - assuming that at a frequency of 1 GHz the impedance is mainly by an inductor;
  - then since its impedance is approximately 6 ohm at this frequency;
  - its value is found to be:

$$L = \frac{X_L}{2\pi f} \cong \frac{6}{2\pi \times 1 \times 10^9} = \frac{6}{2\pi} \text{ nH} \cong 1 \text{ nH}$$

Impedance Characteristics with Frequency

- This shows that, data at higher frequency will be needed in order to determine this value more accurately.
- Thus, in the case of the 100 pF capacitor,
  - when used at a frequency of over 1 GHz
  - it is closer to being an inductor rather than a capacitor.
- If used as a DC block,
  - it must have an impedance of about 5 ohm
  - which is estimated as 1/10 of a standard impedance; considering standard impedance is 50 ohm).

Impedance Characteristics with Frequency

- It is possible to use this capacitor
  - as a DC block or a bypass capacitor between the frequencies of 300 MHz to 900 MHz;
  - but due to the effect of the inductor, its use as DC block at a higher frequency poses a difficulty.

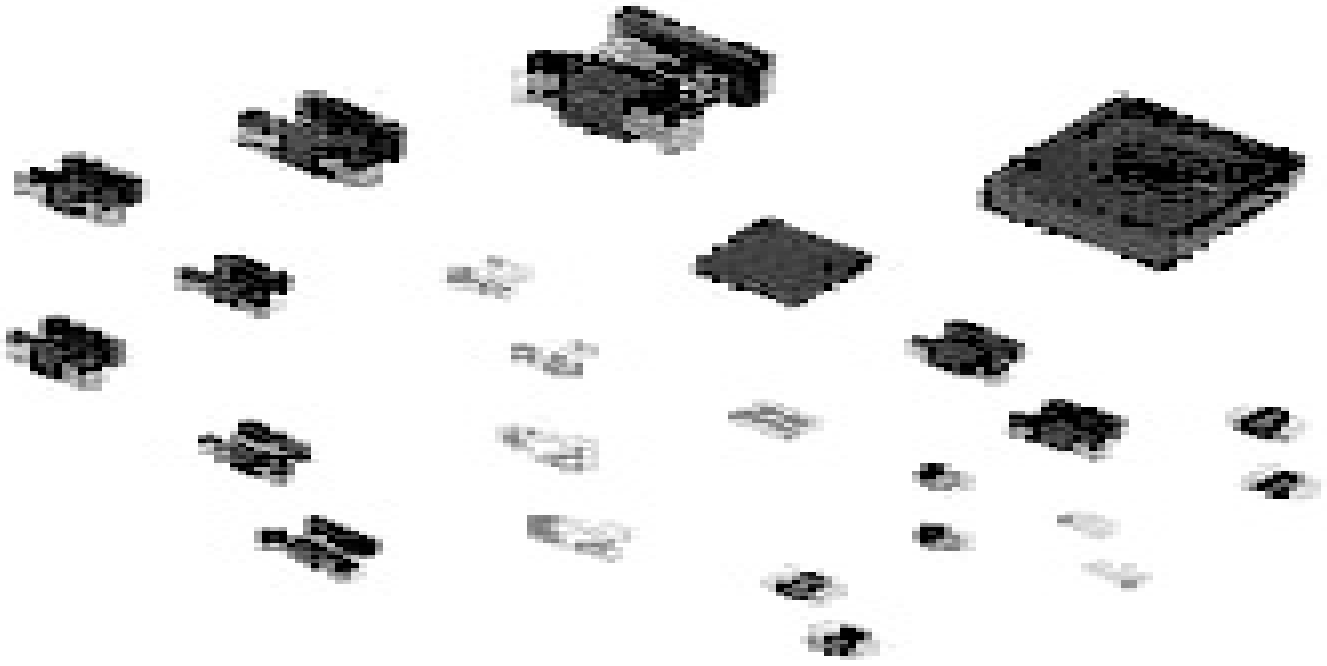
Chip-Type Inductors

- To obtain the inductance,
  - an enamel coated copper wire is wound on a core of ferrite material between the terminals to be soldered.
  - More winding is possible as the diameter of such wire is made a lot thinner,
  - which results in higher inductance.
- It should however be noted that,
  - this will lead to increasing series resistance and
  - decreasing current capacity on the other hand.

Chip Inductors (Murata chip inductors)

- The inductance can be significantly increased by
  - increasing the number of windings;
  - but this will also lead to a proportional increase of parasitic capacitance.
- Therefore,
  - as the inductance becomes larger,
  - they are usually not be used at high frequency and when designing a circuit,
  - there will be the need to use given data to verify the frequency range of operation

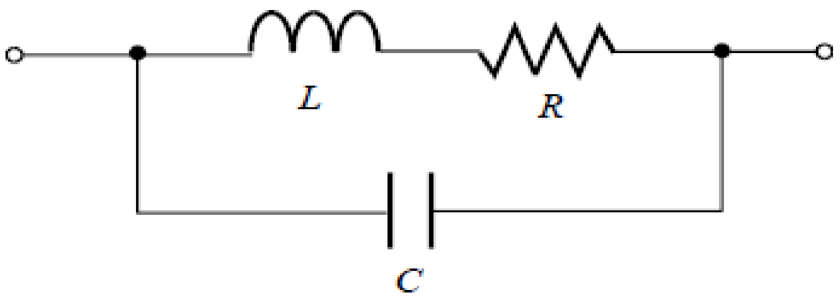
Chip Inductors (Murata chip inductors)



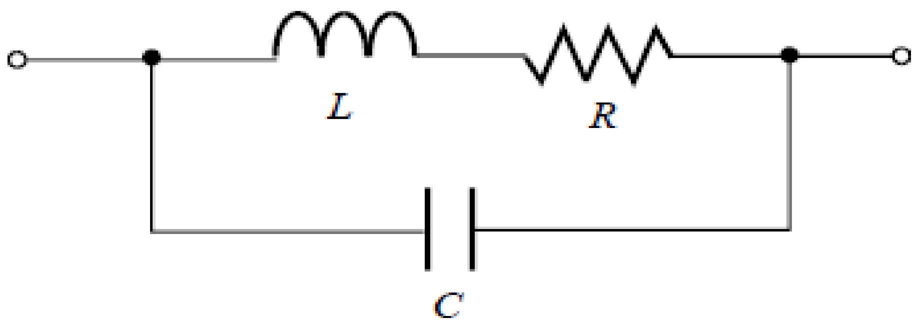
Equivalent circuit of an inductor

KNUST Telecomm. Engineering

- The figure below is a typical electrical equivalent circuit of an inductor;
  - where L represents the inductance arising from the winding and
  - R represents the winding resistance.
  - The C in the equivalent circuit also represents the parasitic capacitance appearing between the windings.



Equivalent circuit of an inductor…



- At extremely low frequency,
  - the inductor usually behaves like a resistor, and
  - as the frequency becomes higher, the reactance due to the inductance arising from the winding also becomes dominant and
  - then it behaves as an inductor.

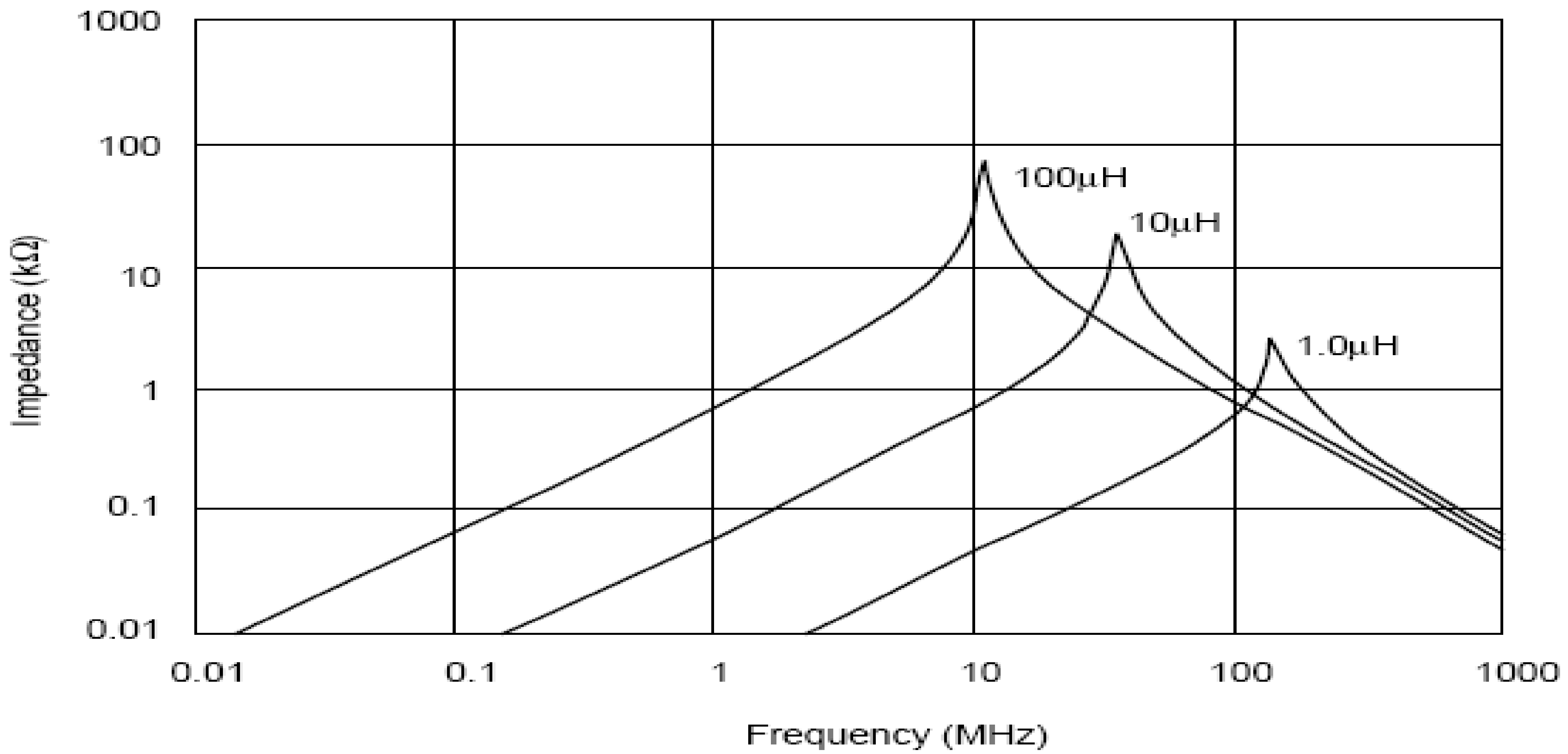
Impedance Characteristic of a Chip-type Inductor

- As the frequency becomes much higher,
  - the impedance of the capacitor connected in parallel becomes smaller and then
  - the inductor behaves as a capacitor.
  - Thus the approximate frequency range for using an inductor is usually:

$$\frac{R}{L} < \omega < \frac{1}{\sqrt{LC}}$$

Impedance characteristics with frequency of a chip inductor (Murata LQH31C)

KNUST
Telecomm.
Engineering



Impedance Characteristic of a Chip-type Inductor

KNUST Telecomm. Engineering

- In this figure, examining the 100 μH curve,
  - it is found that, the impedance increases linearly with frequency up to 10 MHz.
  - Thus below 10 MHz its behavior as an inductor can be verified.
  - Since the impedance value at 1 MHz appears to be approximately 1k ohm, the inductance is found to be:

$$L = \frac{X_L}{2\pi f} \cong \frac{1\times 10^3}{2\pi\times 1\times 10^6} = \frac{1}{2\pi}\ \text{mH} = 159\mu H$$

Impedance Characteristic of a Chip-type Inductor

- As the frequency increases,
  - the impedance begins to fall after reaching a maximum point;
  - which is due to the influence of the capacitor in the equivalent circuit
  - thus, as the frequency becomes much higher, the inductor acts as a capacitor.
- Assuming that at a frequency of 100 MHz it is mainly a capaci-tor; then

$$C = \frac{1}{2\pi f X_C} \cong \frac{1}{2\pi \times 1\times 10^3 \times 100 \times 10^6} = \frac{10}{2\pi}\ \text{pF} \cong 1.59\ \text{pF}$$

Impedance Characteristic of a Chip-type Inductor

- Furthermore, since the resistance is 100 kohm at the maximum point in Fig. 2.11, then the value of the series resistor in the equivalent circuit becomes: [$Z_{eq} = QX_L, Q = X_L/R$]

Thus

$$\frac{(\omega_o L)^2}{R} = 100\ \mathrm{K}$$

and from this a value of

$$R = \frac{(\omega_o L)^2}{100\ \mathrm{K}} = \frac{\left(2\pi \times 10 \times 10^6 \times 100 \times 10^{-6}\right)^2}{100 \times 10^3} = 4\pi^2 \times 10 \cong 390\Omega$$

is obtained.

Chip-Type Resistor

- Chip-type resistor is manufactured by
  - printing a resistive material (RuO_2) on a ceramic substrate and after the conductor pattern has been printed (Thick-film electrode),
  - terminals are plated to make it possible for soldering.
- In order to prevent oxidation or damage to the resistive mater ial;
  - a glassy material is coated on the resistive material in a postprocessi- ng.
- A similar specification to that of capacitors (1005, 1608, and 2010) is used in the identification of chip resistors too.

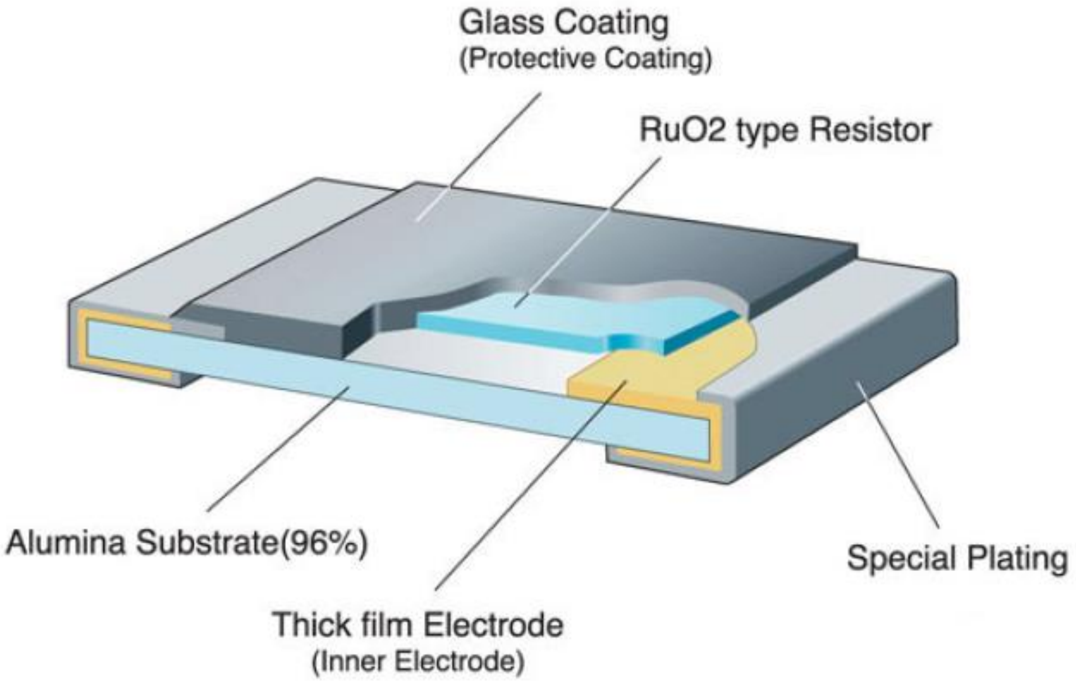
Chip-Type Resistor…

KNUST
Telecomm.
Engineering

- Depending on the manufacturer,
  - the value of the resistor is marked on its surface which makes the identification of the value of the resistor much easier.
- Following a general notation,
  - the first two digits represent the effective value of the resistance and
  - the remaining digits represent the exponent;
  - thus a 3.4k resistor is denoted as:

$$342 = 34 \times 10^2 = 3.4 \times 10^3 = 3.4 \text{ k}\Omega$$

Diagram of a Chip-type Resistor



(a) structure

(b) photo

Frequency Characteristics and Equivalent Circuit of a Chip Resistor

- The frequency characteristics and equivalent circuit of a chip resistor is generally not known.
- This may be determined from impedance measurement
  - from which the equivalent circuit and impedance characteristics can be known.
- However, similar to a capacitor,
  - the impedance characteristics of chip resistors generally becomes more ideal as the size gets smaller.

Equivalent Circuit of Capacitor by Simulation

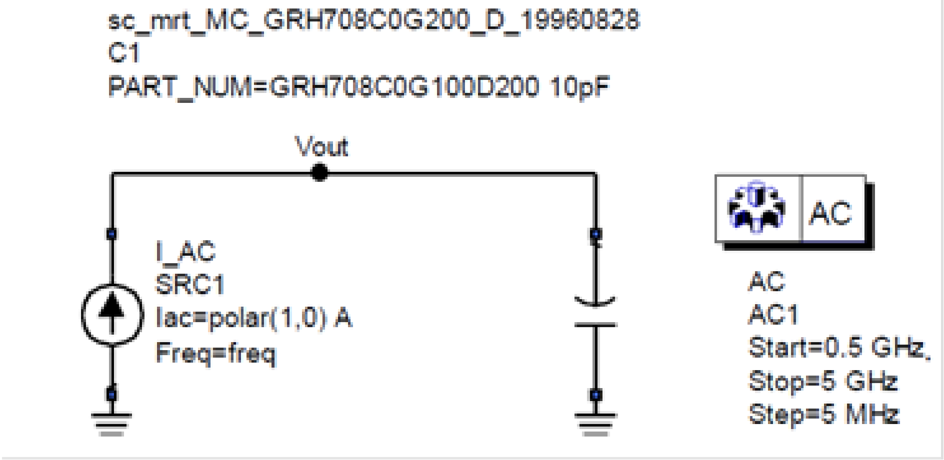
KNUST
Telecomm.
Engineering

Example

- Open the Murata capacitor library in ADS and after measuring the 10 pF impedance by simulation; obtain its equivalent circuit

Solution

- In the schematic, **Vout** becomes the impedance since AC current source is set to1A.

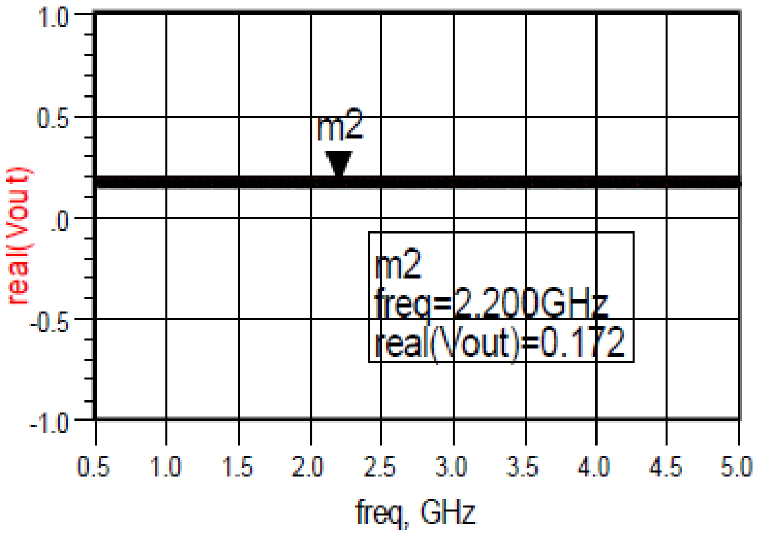


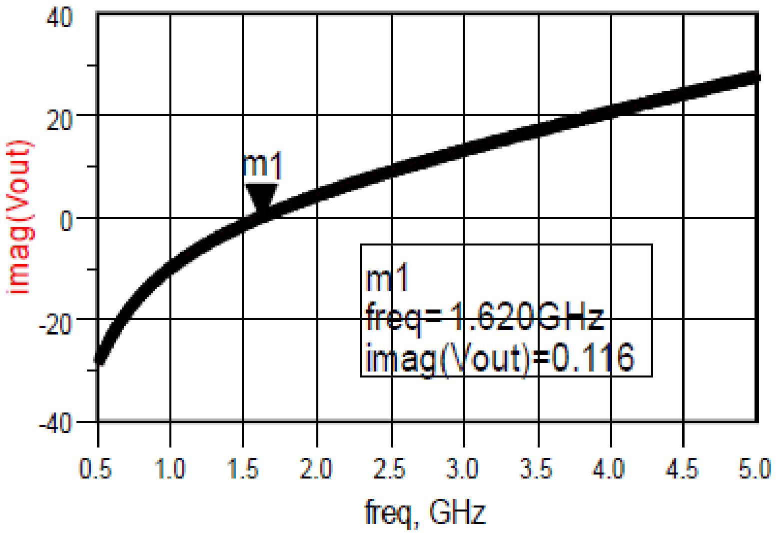
ICnSYS LAB

Equivalent Circuit of Capacitor by Simulation

KNUST Telecomm. Engineering

- Plotting the real and imaginary parts of *Vout* separately,
- the value of the real part is read as $R = 0.17\ \Omega$.





ICnSYS LAB

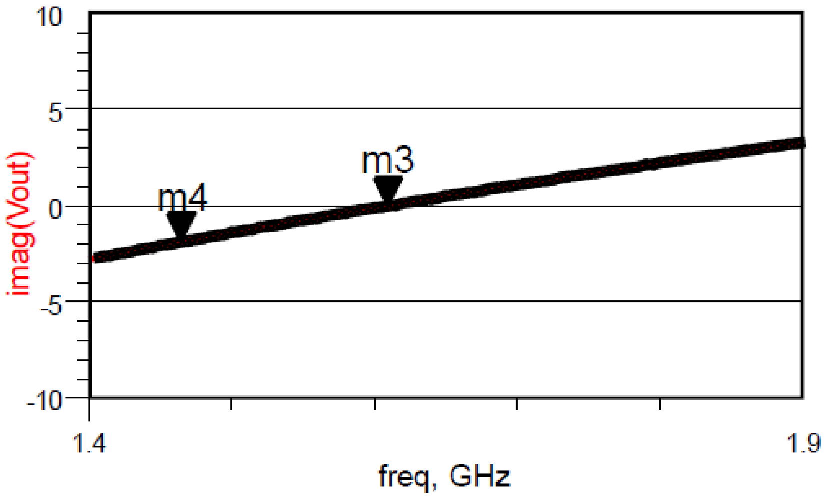
Equivalent Circuit of Capacitor by Simulation

- the slope near the resonant frequency becomes

$$\left.\frac{\partial X}{\partial f}\right|_{f_o} = 2\pi \left.\frac{\partial X}{\partial \omega}\right|_{f_o} = 2\pi \left.\frac{\partial}{\partial \omega}\left(\omega L - \frac{1}{\omega C}\right)\right|_{f_o} = 4\pi L$$

m4
freq=1.465GHz
imag(Vout)=-1.886

m3
freq=1.610GHz
imag(Vout)=-0.007



Eqn L=(m3-m4)/(indep(m3)-indep(m4))/(4*pi)
Eqn C=1/((2*pi*indep(m3))2*L)**
Eqn X=2*pi*freq*L-1/(2*pi*freq*C)

freq	C	L
500.0 MHz	6.763E-12	1.037E-9
505.0 MHz	6.763E-12	1.037E-9
510.0 MHz	6.763E-12	1.037E-9
515.0 MHz	6.763E-12	1.037E-9
520.0 MHz	6.763E-12	1.037E-9
525.0 MHz	6.763E-12	1.037E-9
530.0 MHz	6.763E-12	1.037E-9

Equivalent Circuit of Capacitor by Simulation

KNUST
Telecomm.
Engineering

- Comparison